# Facies changes and paleogeographical implications in the Serravallian of the Lagos-Portimão Formation (Praia da Rocha, southern Portugal)

## *Cambios de facies e implicaciones paleogeográficas en el Serravalliense de la Formación Lagos-Portimão ( Praia da Rocha, Sur de Portugal)*

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**Abstract:** Detailed stratigraphic control and lateral tracing of facies between Praia da Rocha and the adjacent Praia do Vau evidenced that, although the thickness of layers remains essentially homogeneous, the internal composition, grain size and fossil contents change noticeably. Three orders of sequences were distinguished. Smaller-scaled sequences were produced by storms (event beds). Second order sequences are interpreted as generated by a Milankovitch forcing. The larger scale one is observed by the piling of subunits, with assumed eustatic forcing. The prevailing W/SW orientation of paleocurrents measured, and the overall model of dispersion systems, fit in an estuarine pattern of circulation during the Middle Miocene in the North-Betic Strait. Local, gentle diapiric up-warping between Portimão and Albufeira also contributed to water-depth and facies changes.

**Key words:** Lagos-Portimão Formation, Serravallian, Algarve, Portugal.

***Resumen:*** *Un control estratigráfico detallado y el seguimiento lateral de los cambios de facies entre las Playas da Rocha y do Vau pone de manifiesto que, aunque las potencias de las capas se mantienen poco más o menos constantes, la organización interna, el tamaño de grano y el contenido fosilífero varía notablemente. Se distinguen tres órdenes de secuencias: las de menor escala son capas de evento producidas por tormentas, las de segundo orden se interpretan como originadas por cambios orbitales de tipo Milankovitch y las de mayor orden, marcadas por el apilamiento de unidades, se consideran de origen eustático. El sentido de las paleocorrientes, predominante hacia el W/SW, y la distribución de los sistemas de dispersión encajan en el modelo de circulación de tipo estuarino propuesto para el Estrecho Nord-Bético durante el Mioceno Medio, aunque algunos abombamientos diapíricos entre Portimão y Albufeira contribuyeron a los cambios de profundidad y de facies.*

***Palabras clave:*** *Formación Lagos-Portimão, Serravalliense, Algarve, Portugal.*

## INTRODUCTION

The Miocene Lagos-Portimão Formation (LPF) is an up to 60-m-thick unit made up of skeletal packstones/grainstones and rudstones deposited on a temperate, mixed carbonate-siliciclastic shelf (Antunes *et al*., 1990; Antunes & Pais, 1992; Pais *et al*., 2000; Legoinha, 2001; Forst, 2003, Brachert *et al*., 2003; Kroeger *et al*., 2007). These deposits are arranged in laterally continuous beds exposed along the cliffs of the coast of Algarve (Southern Portugal) between Lagos and Olhos de Água (Fig. 1). The LPF rests unconformable on the Paleozoic and Mesozoic basement of the Caldeirão Mountains, which is the present day expression of the Neogene hinterland adjacent to the relatively narrow shelf during the lower and middle Miocene. The LPF was covered by unconformable Tortonian siliciclastic prone sediments (Fig. 2).

Previous interpretations considered that the LPF accumulated on a narrow, flat shelf surrounding the mountains of southern Portugal (Fig. 1), subjected to high-frequency eustatic cycles that caused synchronous vertical changes of facies recorded along the whole shelf. These tabular units can be traced over 40 km, and the presumed monotonous thickness and lithology was thought to result from an outcrop orientation essentially parallel to the depositional strike, i.e., the elongation of the shelf (Brachert *et al*., 2003, Kroeger *et al*., 2007). Therefore, the sections presented were considered representative for the whole extent of the LPF. However, detailed stratigraphic and sedimentological analyses of the LPF deposits suggest a more refined model that obviously incorporates some previous hypotheses.

## FIELD OBSERVATIONS

Examination of facies between Praia da Rocha and the adjacent Praia do Vau sections, less than one kilometre away (Fig. 1), evidenced that, although the thickness of layers remains essentially homogeneous, textures and fossil contents change noticeably (Fig. 2). Maximum abundance of fossils ranges from 55 to 75%, with paucispecifical and multispecifical shell concentrations of clypeasteroids, echinoids, bryozoans, oysters, pectinids, and gastropod moulds.

This is particularly evident in the transition of coarse skeletal rudstones (SR, following Bachert *et al*.,'s 2003 terminology) forming the middle and upper part of Praia da Rocha section into fossiliferous sandstones (FS) and SR arranged in coarsening upward sequences in Praia do Vau. Five subunits are distinguished.

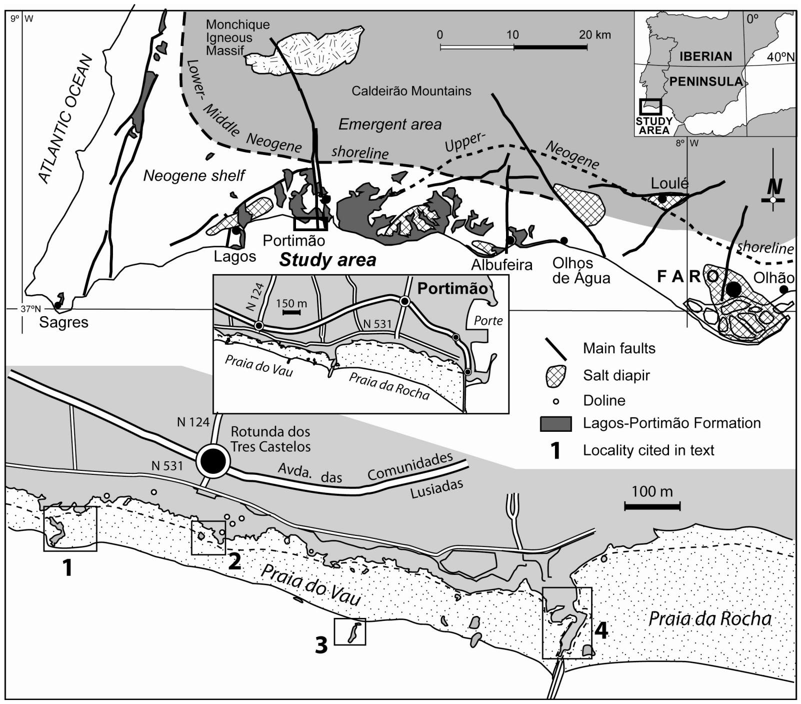


FIGURE 1. *Schematic map of southern Portugal with outcrops of LPF, and detail map of Rocha and Vau Beaches with localities cited in the text.*

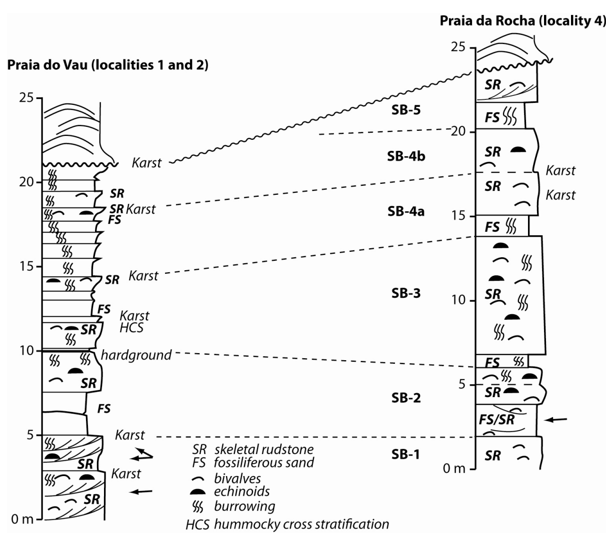


FIGURE 2. S*ections measured in Rocha (locality 4) and Vau Beaches (localities 1 and 2), with correlation and subunits (SB) distinguished.*

***Subunit 1***.- Large-scale cross-bedded, skeletal coarse FS and SR. Abundant *Thalassinoides* structures greatly blurs the original physical sedimentary structures. Additionally, interstratal karstification along some bedding and interset planes adds further complication, making observation difficult. The thickness of cross bedded sets in excess of one meter and the spatial arrangement and overall geometry of sedimentary bodies indicate migration of large scale bedforms fed by skeletal sands deposited in the nearshore. The absence of mud is attributed also to winnowing of fines by currents. The overall pattern indicates nearshore bars on a high-energy shelf swept by prevailing west-moving regional currents.

***Subunit 2***.- Includes two neatly separated intervals. The lower interval (2.5 m thick) consists of burrowed (*Thalassinoides*) yellow sandstone with scattered fossil remains. In Praia da Rocha (4 in Fig. 1) skeletal grains are of greater size than in localities 1, 2, and 3, and this interval consists of trough cross-bedded SR. The upper interval has variable composition: In Praia da Rocha, these are SR, but grain size decreases toward Praia do Vau (loc. 3 and 2); then it changes to (loc. 1) a vertical pile of coarsening upward (CU) sequences of FS and SR that begin with white colours but change vertically to light grey and reddish (the latter owing to the partly weathered, more calcareous lithology). The uppermost part is a hardened, intensely burrowed layer of SR facies that is considered an incipient hard ground. The overall pattern is of a shallow marine accumulation of intensely burrowed skeletal packstone and grainstone that changes to finer grained, burrowed, CU sequences with blurred bedding. This is interpreted to reflect the transition, in a SW direction, to deeper settings of a ramp where currents scarcely swept the bottom and wave winnowing was strongly reduced.

***Subunits 3, 4 and 5***.- The piling of metre-thick yellow FS and FR found in loc. 4 changes laterally into a repetition of decimetre-thick CU sequences of FS and SR (Fig. 2), in the same way as Subunit 2.

## MICROFACIES

Most microfacies are fine, rarely medium, skeletal packstones/grainstones with some intercalated SR. Some samples show poorly sorted and concentrated fossil remains. Quartz (silt to medium sand, ranging from 5 to 25%), detrital and authigenic glaucony, pellets, foraminifers (*Globigerina*, *Globigerinoides*, *Heterostegina*, Miliolids, Nonionids, Textulariidae), echinoids, bivalves (Ostreids, Pectinids) and some gastropods, bryozoans (more abundant in the finest facies, with less skeletal components), brachiopods, ostracods, green algae, are common. Interparticle cement includes anhedral, inequigranular mosaics of calcite. Interparticle and intraparticle moldic porosities are frequent.

## AGE

Previous authors assigned ages from Burdigalian to Serravallian for the various sections of LPF based on the available fossils and also on Sr-isotope stratigraphy (Antunes *et al*., 1997, Legoinha, 2001, Forst, 2003). The occurrence of *Orbulina universa* in subunit 1 of Praia do Vau, first found in this research, allows assigning the whole LPF at Rocha and Vau to the Serravallian. An exhaustive micropaleontological investigation is under way.

## STRATIGRAPHIC ARCHITECTURE

Three orders of sequences have been separated. The smaller-scaled sequences are event beds produced by storms, locally preserved despite intense burrowing.

Second order sequences are observed in subunits 3 to 5 of Praia do Vau (Fig. 4, loc. 3). Those consist of a dominantly sandy, yellow lower part (FS) with bryozoans and *Thalassinoides* burrowing. Locally almost obliterated undulating lamination, mainly of the HCS type, has been preserved. In gradual transition, they pass upward into SR facies with large specimens of *Pecten*, *Ostrea*, echinoids (*Scutella*, *Clypeaster*), algal rhodolites, *Balanus*, etc. These sequences are assigned preliminary here to a Milankovitch forcing. The lower part of the cycle corresponds to more humid, stormier conditions, with larger supply of sand. The upper part of the cycle represents more arid periods, when reduced terrigenous input favours accumulation of shells.

Sequences of the largest scale are represented by the piled subunits with repeated surfaces marking rises of sea level at the base of yellow FS layers (Fig. 3, loc. 4). These are punctuated by the accumulation of second-order sequences supposed to represent times of more stable sea levels.


FIGURE 3. *Praia da Rocha section (locality 4).*

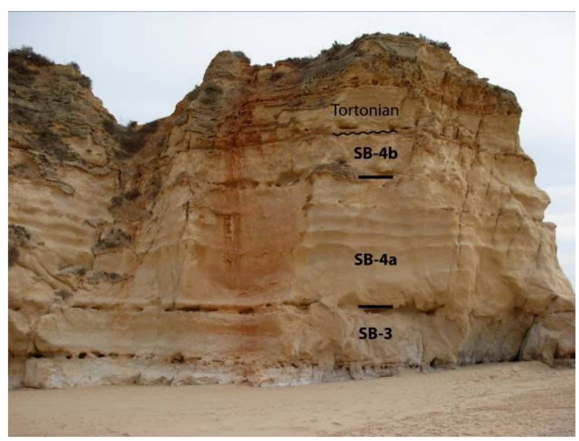


FIGURE 4. *Praia do Vau section (locality 2).*

The proposed 3D architecture and internal organization of deposits, is thought to record events of sea level rise separated by more stable sea levels with an assumed pervasive orbital forcing that has not been proved conclusively. Besides, local changes in bathymetry favoured the occurrence of topographically higher areas where wave and current winnowing produced the disorganized coarse-grained facies, whereas somewhat deeper areas recorded better the changing energy of storms with a Milankovitch forcing.

## PALEOGEOGRAPHY

The Miocene Mediterranean Sea was connected to the west to the Atlantic Ocean via the North-Betic and the South-Riffean straits. To the east, it was connected to the Indo-Pacific Ocean until the colliding European and African plates closed this passage turning the Mediterranean into a marginal sea, and modifying the patterns of water circulation in the North-Betic strait. An estuarine model of circulation existed during the Middle Miocene, when diatomitic facies (“moronitas”, “albarizas”) witness the abundance of nutrients and high productivity on the southern flank of the North-Betic Strait (Sierro *et al.*, 1989, Sierro and Flores, 1992). The model assumes a superficial Mediterranean outflow into the Atlantic, with regional direction SW, and a deep current entering the Mediterranean from the Atlantic (Fig. 5). Prevailing W/SW orientations of paleocurrents measured in subunits 1 and 2, and the overall model of dispersion systems fit in the estuarine pattern.

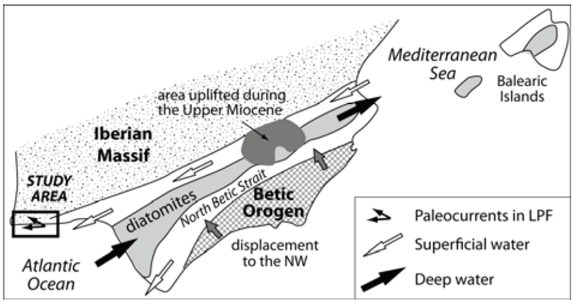


FIGURE 5. *Paleoceanographic scheme of the Atlantic-Mediterranean communication through the North-Betic Strait during the Lower-Middle Miocene (modified after Sierro and Flores, 1992)*

A key point of the presented model of Algarvian shelf is that, besides the larger-scale sea level changes, local irregularities, such as the salt domes (diapirs) between Portimão and Albufeira, created gentle (subtle) up-warping that conditioned water depth and, hence, facies changes even at short distances, but without appreciable changes of thickness, a mechanism suggested by Forst (2003) to explain changes in bathymetry responsible for deposition of Neogene units and the intervening discontinuities. In addition, it is proposed here that currents sweeping the shelf tended to accelerate off coastal protrusions or over shallower parts (shoals), eroded the bottom and deposited decelerations carpets in down current areas where the flow decelerates and transport capacity decreases, as shown by Swift and Thorne (1991). In Southern Portugal, currents flowing out of the North-Betic Strait moved sediment to the west, magnifying the Coriolis deviation on storm surge ebbs. The direction of facies changes described for the LPF is SW.

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